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FOR

SERIAL DEVICE DAISY CHAINING METHOD AND APPARATUS

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## SERIAL DEVICE DAISY CHAINING METHOD AND APPARATUS

### FIELD OF THE INVENTION

This invention relates to the field of communications. In particular, this invention is drawn to communication between a bus master and  
5 associated serial devices.

### BACKGROUND OF THE INVENTION

Several communication techniques are available for enabling communication between a processor or a bus master and a plurality of serial devices coupled to the processor. Typically, the processor communicates with  
10 one or more serial devices sharing a common communication bus. In the event the processor needs to communicate information to a specific serial device, the processor must be able to distinguish the devices from each other. Various techniques are available to enable individual identification or selection of the serial devices.

For example, a separate select line may be used to enable each serial  
15 device. The serial devices are capable of responding or acting on information communicated when their respective select lines are asserted. One disadvantage of this technique is the imposed requirement for dedicated pins or exclusive signal lines on the processor to handle the device select signals.  
20 In particular, a separate select signal line is required for each serial device to be uniquely enabled.

Another technique uses jumpers, switches, or other hardware mechanisms associated with the serial devices to permit assignment of a unique identifier for each serial device. Each serial device only responds to

commands with an accompanying identifier that matches that of the serial device as determined by the jumpers, switches or other hardware.

One disadvantage of this technique is that knowledge of other devices in the system is necessary to avoid duplicate device identifier assignments.

- 5 Serial devices cannot be simply replaced or added into the system without first assigning a unique identifier. In addition, each device must have the ability to be configured for any one of a number of potential identifier assignments. For integrated circuit based serial devices additional packaging pins may be required to enable the serial device to support more than one
- 10 potential identifier assignment.

## SUMMARY OF THE INVENTION

In view of limitations of known systems and methods, methods and apparatus of selecting serial devices having a common bus for communication with a bus master are described. The bus master designates the targeted serial device(s) for execution of a command sequence through the use of device selects and a channel identifier embedded in the command sequence.

The serial devices compare their respective received channel identifiers with a common pre-determined value. In one embodiment, the pre-determined value is selected from the set {x0h, xFh}. If the received channel identifier matches the pre-determined value, the device executes the command sequence. The choice of daisy chain or normal mode configuration determines whether an immediate source for the command sequence is the bus master or a preceding serial device in the daisy chain. Instead of assigning an individual unique static address to each serial device for comparison with a channel identifier communicated to all the serial devices, the devices use the same common pre-determined value for comparison with a received channel identifier. Methods for operating and apparatus incorporated into the serial devices enables implementation in either a daisy chain or a normal connectivity configuration such that only the bus master's operation is dependent upon the selected configuration

A method includes the step of serially providing a command sequence having a first channel identifier to a first device of a plurality of daisy chained devices. The first channel identifier is modified to generate a second channel identifier for transmission to the next device in the daisy chain.

A serial device apparatus includes a serial input port for receiving a first command sequence having a first channel identifier and a remaining command sequence. The serial device further includes a daisy chain output port and command sequence processing logic. The command sequence  
5 processing logic modifies the first channel identifier to form a second channel identifier. The second channel identifier and the remaining command sequence are provided to the daisy chain output port.

Other features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description  
10 that follows.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

5        Figure 1 illustrates a plurality of serial devices coupled to a serial bus master.

Figure 2 illustrates a plurality of daisy chained serial devices coupled to a serial bus master.

10       Figure 3 illustrates a method of operating the bus master in one of a daisy chain or a normal mode.

Figure 4 illustrates circuitry enabling daisy chain operation for individual serial devices.

Figure 5 illustrates one embodiment of a method of operating the individual serial devices in response to the received serial communications.

15       Figure 6 illustrates one embodiment of a command sequence protocol for the daisy chain mode of operation.

Figure 7 illustrates the transmitted CID provided from a first serial device to a second subsequently daisy chained serial device based on the CID received by the first serial device.

20       Figure 8 illustrates an embedded CID state diagram as the CID passes through daisy chained serial devices.

## DETAILED DESCRIPTION

Figure 1 illustrates one embodiment of a bus master 110 coupled to a plurality of serial devices 120-150 sharing a common serial communications bus 160. The serial communications bus 160 carries commands, addresses, and data between the bus master and the serial devices using a command sequence protocol. Typically, the commands include read and write commands associated with specific addresses.

In this embodiment, communications bus 160 includes a clock signal (SCLK 162), a serial data in (SDI 164) to the serial devices from the serial data out (SDO) of the bus master, and a serial data out (SDO 166) from the serial devices to the SDI of the bus master. Commands, addresses, and data are effectively broadcast to all other devices sharing the same serial communications bus.

In order to select a specific serial device for acting on a command or responding to other information communicated on the bus, the serial devices are selectively enabled by a device select signal. In one embodiment, the serial devices include integrated circuit packages and the device select signals are referred to as device select signals.

Each serial device has a device select input (CS) that is asserted to indicate that the device should respond to information being broadcast on the serial communications bus. In order to support unique identification of a plurality of serial devices using the device select signals, bus master 110 must be capable of providing individual device selects, one for each serial device. In the illustrated embodiment, bus master 110 includes a separate device

select signal (e.g., CS 172, CS 174, CS 176, CS 178) to enable selecting any one of the serial devices 120-150 uniquely.

The information is serially broadcast to the plurality of devices using a communication protocol consisting of command, address, and data words.

- 5 Each transmitted bit is communicated substantially simultaneously to all the serial devices. Clock signal SLK 162 is provided by bus master 110 for synchronous transmission of the information. The device selects are used to identify the intended recipients of the command, address, and data words.

- 10 Figure 2 illustrates a bus master 210 coupled to a plurality of serial devices 220-250 sharing a common serial communication bus 260. In this embodiment, the plurality of serial devices are coupled in "daisy chain" fashion with respect to the SDI signal. The SDI signal is not part of the shared communication bus 260. The devices are "daisy-chained" such that the SDI input for any serial device is provided by the SDI THRU output of a preceding device in the chain, with the exception of the first device 220 in the chain which receives its SDI signal from the SDO of the bus master 210. In particular, the serial device input port is coupled to the SDI\_THRU output port of a preceding device or the bus master. Each serial device receives its SDI signal from a preceding device rather than from the serial
- 15
- 20 communication bus 260.

As illustrated, the SDI input for the first device is provided by the bus master. Thus, the SDI 222 of serial device 220 is provided by bus master 210. The SDI 232 of serial device 230 is provided by SDI THRU 224 of preceding serial device 220. The SDI 242 of serial device 240 is provided by SDI THRU



234 of preceding serial device 230. Finally, SDI 252 for serial device 250 is provided by SDI THRU 244 of preceding serial device 240.

The serial communication bus 260 in common with all devices 220-250 includes the SDO 264 and SCLK 262 signals. All the serial devices in a group  
5 share the same device select signal 272. A bus master with a plurality of device selects allows for handling more than one group of serial devices.

Given that the device select is shared with all serial devices in the same group, other mechanisms must be used to differentiate between devices in the same group. In one embodiment, the communication protocol embeds a  
10 device or channel identifier (CID) into the command sequence to uniquely identify a specific device or channel when the devices are daisy chained.

Generally, instead of providing a static address for each serial device, the serial device addresses are determined inherently by the device distance from the bus master measured in terms of other serial devices. Each serial  
15 device compares its received channel identifier with a pre-determined value to determine whether it has been selected. The CID is modified as it cascades through the daisy chain. This permits all serial devices to compare their respective received CIDs with the same pre-determined value. In various embodiments, the pre-determined value is selected from the set {x0h, xFh}.

20 The devices, however, do not distinguish between daisy chain mode or normal mode in terms of behavior. Accordingly, the behavior of the bus master with respect to device selection and device addressing must change depending upon whether the devices are coupled in daisy chain fashion.

Figure 3 illustrates a method of operating the bus master to support  
25 either daisy chain or normal communication mode. Step 310 determines the

mode of operation. This is determined by the system designer. In one embodiment, a register bit is used to inform the bus master about the selected mode.

If the devices are connected in daisy chain fashion, then the bus master must communicate with the devices in a "daisy chain" mode. The bus master must assert the device select of the selected or targeted serial devices in step 320. Due to the daisy chain implementation, at a minimum all of the serial devices preceding the targeted serial device(s) in the daisy chain must have their corresponding device selects asserted. Typically, all the daisy chained devices will share the same device select as illustrated in Figure 2. The command sequence is distributed to the plurality of serial devices in step 330. The daisy chained devices receive a command sequence at substantially the same time with delays introduced only as a result of propagation delays through any preceding device in the chain.

If devices are not connected in a daisy chain configuration, then the bus master must assert the device selects of the targeted serial devices to the exclusion of the non-targeted devices in step 340. The same command sequence is then issued substantially simultaneously to the serial devices in step 350.

The serial devices do not distinguish between normal or daisy chain modes of operation because this is determined by the interconnection of the devices. The bus master can use the CID and/or the device selects to identify the targeted devices. In the daisy chain mode, however, the device selects are shared and thus cannot uniquely identify devices. Thus the CID is required in the daisy chain mode. In the normal mode, all the devices receive the

same CID, thus the device select is used to uniquely identify devices. Thus neither the device select nor the CID can be used exclusively to identify targeted devices. Instead, both the device selects and the CID are used to identify the device.

5           Only the behavior of the bus master must change between the two modes. In particular, the CID provided by the bus master in the command sequence changes depending upon the mode of operation.

When in daisy chain mode, the bus master provided CID typically must specifically identify the targeted serial device. The shared device selects  
10           are all asserted and thus cannot exclusively target a unique device. Thus in one embodiment, step 330 must ensure that the command sequence specifies the CID of the targeted device.

When in normal mode, the bus master provided CID matches the pre-determined value used for comparison by each serial device. Even though all  
15           devices receive the same CID, only those devices with their device selects asserted will be targeted. Thus in one embodiment, step 350 provides a command sequence specifying the pre-determined comparison value of all the devices as the CID.

In one embodiment, the communication protocol supports a broadcast  
20           option. The broadcast option may be indicated by the command sequence. The serial devices will ignore the CID when the broadcast option is detected. When operating in daisy chain mode, the bus master specifies the CID of the targeted device or ensures the broadcast option is selected to target all devices in step 330. When the bus master is operating in normal mode, the broadcast  
25           option has little effect. Given that the broadcast option renders the CID value

irrelevant, however, the bus master may provide a CID other than the pre-determined comparison value when the broadcast option is selected in step 350.

Figure 4 illustrates a plurality of daisy chained serial devices including the internal logic to generate modified CIDs for subsequent devices in the chain. The interconnection between the devices determines the mode of operation. In particular, the SDI input ports receive everything directly from the bus master in normal mode. In daisy chain mode, however, the SDI input of one device is the SDI THRU of another device. The command sequence is serially clocked from the bus master to the SDI input of the first serial device in the daisy chain. The SDI THRU 432 output of the first device 400A is provided to the SDI input of the next device in the chain and so on until the last device, 400N.

Command sequence execution logic 430 interprets and executes the command sequence, if the device has been selected as determined from the command sequence (i.e., either the broadcast option is selected or the CID indicates this device is selected). Command sequence processing logic 420 receives the incoming command sequence. Command sequence processing logic 420 extracts the CID for device 400A and modifies the CID and therefore the command sequence for transmission to the next device in the daisy chain.

Figure 5 illustrates the operational behavior of the serial devices. If the device select signal is not asserted as determined by step 520, then the device ignores the command sequence as indicated by step 570. If the device select is asserted, however, step 530 determines whether the broadcast option has been

selected from the command sequence. If so, then the device executes the command sequence irrespective of the CID as indicated by step 560.

If the broadcast option is not selected, the command sequence processing logic extracts the CID from the received command sequence in step 540. The command sequence processing logic modifies the received CID (and therefore the command sequence) and provides the command sequence with the modified CID as its SDI\_THRU output for transmission to the next device in the daisy chain in step 546. In particular, the device receives a first command sequence having a first CID and a remaining command sequence.

The command sequence processing logic modifies the first CID to form a second CID. The command sequence processing logic generates a second command sequence from the second CID and the remaining command sequence for use by the next device in the daisy chain.

The modification step enables a simple addressing and detection scheme. In one embodiment, the first CID is decremented to generate the second CID. In an alternative embodiment, the first CID is incremented to generate the second CID.

If a device's received CID indicates that the device has been selected in step 550, the command sequence is acted on in step 560. Otherwise, the command sequence is ignored in step 570. A determination of whether the device is the selected device can be achieved by comparing the received CID with a pre-determined value such as x0h or xFh. Rather than programming each device with a unique address for comparison with a commonly received CID, the devices can use a common pre-determined comparison value because the serial CID modification scheme ensures each device receives a

unique CID when the devices are in a daisy chain mode. Due to the nature of the daisy chain, however, there is only a single clock cycle delay permitted between receipt of a bit and transmission of the bit to the next device.

Accordingly, the command sequence protocol must be designed to permit serial modification within the window of opportunity presented by the daisy chain configuration.

Figure 6 illustrates one embodiment of a command sequence protocol. The command sequence protocol consists of control 610, address 620, and data 630, 640 words. As indicated by timing diagram 660, each command sequence 650 begins with a control word followed by an address word and then one or more data words.

In the illustrated embodiment, each address and data word is 8 bits long. The command word includes a bit (C7) to indicate whether the broadcast mode is enabled such that any CID address can be ignored. R/W bit (C6) indicates whether the command is a read or a write command. Bit C5 indicates the addressing mode, direct or indirect. One bit is reserved for future use (C4). The remaining bits represent the embedded CID. Although the command sequence is transmitted in most significant bit (msb) order, the CID is stored in least significant bit (lsb) order within the command word to facilitate CID modification within the modification window.

The  $i+1^{\text{th}}$  device receives the  $k^{\text{th}}$  bit of the command sequence cascaded thru the  $i^{\text{th}}$  device. Accordingly, the  $i+1^{\text{th}}$  device starts receiving the CID before the  $i^{\text{th}}$  device has received all of it. Modification of the CID must take place without knowledge of the entire word during daisy chain mode. The CID can be incremented or decremented within a single clock cycle. In order

to properly increment or decrement the CID serially, however, the bits must be provided least significant bit first. A serial adder or serial subtractor circuit can thus provide the requisite modification within the one bit delay window.

Figure 7 illustrates one embodiment of CID embedding and

5 modification for a four bit CID. The CID column 710 identifies the 4 bit values assigned to the devices beginning with the device adjacent to the bus master and counting along the daisy chain away from the bus master. The values of column 710 are presented in most significant bit (msb) form. The embedded command word received column 720 illustrates the corresponding  
10 CID of column 710 as it would be embedded in lsb order. This is the value that the bus master must embed in order to select the corresponding device. The embedded command word transmitted column 730 illustrates the value that the CID of column 720 will be modified to.

15 In this example, each device compares the received command word with the value x0h to determine if it has been selected. The value "0000" will result in the selection of the device adjacent the bus master in the daisy chain.

Figure 8 illustrates table 700 in another form. Each CID state 802, 804, 806, etc. has a value corresponding to a given device's received CID. The given device modifies its received CID to the value indicated by the next state  
20 (following the direction of the arrows). The inner circle of numbers represents the associated channel or device identifier counting away from the bus master. To target device 16, for example, the bus master should provide a command sequence with the embedded CID value "1111." Starting at this state (804) and counting each state until the value "0000" is reached, one can

see the transitions made in the CID as it passes from device to device in the daisy chain until the value "0000" is reached at the 16<sup>th</sup> device.

The enhanced daisy chain methods and apparatus enable addressing serial devices by their relative distance from a bus master. There is no need to set pins or switches on each individual device. This daisy chain technique ensures each serial device is inherently assigned a unique address. The behavior of the individual serial devices is independent of the daisy chain or normal mode of configuration. The bus master, however, must control the device selects and the CID in a manner determined by whether the devices are daisy chained or not.

In various embodiments, the serial devices may be packaged such that more than one device resides within a common integrated circuit package. Thus a plurality of channels may be associated with a single integrated circuit package. In such cases, the channel identifier is modified by each device as it passes through the daisy chained devices within the integrated circuit package such that the channel identifier may be modified more than once as it progresses from an SDI input of the integrated circuit package (going to the first device in the daisy chain) thru a plurality of daisy chained devices within the package to an SDI\_THRU output of the integrated circuit package (associated with the last device in the daisy chain).

In the preceding detailed description, the invention is described with reference to specific exemplary embodiments thereof. Various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the claims. The specification and



Category	Sub-category	Value	Unit	Value	Unit	Value	Unit	Value	Unit
Energy	Electricity	1000	kWh	1000	kWh	1000	kWh	1000	kWh
	Gas	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
Water	Water	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
	Wastewater	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
Waste	Waste	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
	Waste	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
Other	Other	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>
	Other	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>	1000	m <sup>3</sup>